CLAIMS

What is claimed is:

1. A fiber-based optical low-coherence reflectometer comprising:

a polarization-maintaining source path;

a polarization-maintaining reference path;

a polarization-maintaining sample path optically aligned with a collimating lens, a variable wave retarder, and a focusing lens, wherein the focusing lens is disposed to focus light on a sample; and

a polarization-maintaining detection path,

wherein the polarization-maintaining source path, reference path, sample path and detection path are each connected to a polarization-maintaining path coupler.

2. The fiber-based optical low-coherence reflectometer of claim 1, wherein the polarization-maintaining path coupler separates light into polarization-maintaining sample and reference paths while maintaining energy separation of optical signals.

3. The fiber-based optical low-coherence reflectometer of claim 1, wherein the polarization-maintaining source path comprises:

a first polarization-maintaining fiber having a first end and a second end, wherein the first end of the first polarization-maintaining fiber is coupled to a light source and the second end is connected to a polarizer that splits the light source into a first and second polarization channels with independent phase components; and

a second polarization-maintaining fiber having a first end and a second end, the first end connected to the polarizer and the second end connected to the polarization-maintaining path coupler.

4. The fiber-based optical low-coherence reflectometer of claim 1, wherein the polarization-maintaining reference path comprises:

a third polarization-maintaining fiber having a first end and a second end, the first end connected to the polarization-maintaining path coupler, the second end connected to a phase modulator; and

a fourth polarization-maintaining fiber having a first end and a second end, the first end connected to the phase modulator, the second end to a connector and optically aligned with a first collimator that collimates light emitting from the second end of the fourth polarization-maintaining fiber into an optical delay line.

5. The fiber-based optical low-coherence reflectometer of claim 1, wherein the polarization-maintaining sample path further comprises a fifth polarization-maintaining fiber having a first and a second end, the first end connected to the polarization-maintaining path coupler, the second end to a connector and optically aligned with a second collimator that collimates light emitting from the second end of the fifth polarization-maintaining fiber to the variable wave retarder and the focusing lens.

6. The fiber-based optical low-coherence reflectometer of claim 1, wherein the polarization-maintaining detection path comprises:

a sixth polarization-maintaining fiber having a first end and a second end, the first end connected to the polarization-maintaining path coupler, the second end aligned with a third collimator that collimates light emitting from the sixth polarization-maintaining fiber onto a polarizing beam splitter, wherein the polarizing beam splitter splits light from the sixth polarization-maintaining fiber into a first beam and a second beam that are mutually orthogonal and capable of producing a first and second output signal.

7. The fiber-based optical low-coherence reflectometer of claim 6, wherein the first beam of the detection path is detected by a first photodetector and produces the first output signal and the second beam of the detection path is detected by a second photodetector and produces the second output signal.

8. The fiber-based optical low-coherence reflectometer of claim 1, wherein the polarization-maintaining detection path further comprises:

a first and second output signal pass from a first and second photodetector, each output signal pass having a bandpass filter and amplifier to produce a first and a second filtered signal;

an analog-to-digital converter connected to the bandpass filter-amplifier; and

a processor connected to the analog-to-digital converter.

9. The fiber-based optical low-coherence reflectometer of claim 8, wherein the analog-to-digital converter is a two channel 12-bit analog-to-digital converter.

10. The fiber-based optical low-coherence reflectometer of claim 1, wherein variation of the variable wave retarder is from zero to one wavelength.

11. The fiber-based optical low-coherence reflectometer of claim 3, wherein the light source is a broadband light source.

12. The fiber-based optical low-coherence reflectometer of claim 3, wherein the light source is an optical semiconductor amplifier.

13. The fiber-based optical low-coherence reflectometer of claim 3, wherein the polarizer is a fiber bench polarizer.

14. The fiber-based optical low-coherence reflectometer of claim 1, wherein back reflected light from the polariation-maintaining reference and sample path mix at the path coupler to form interference signals.

15. The fiber-based optical low-coherence reflectometer of claim 1, wherein the fiber-based optical low-coherence reflectomoter is used to characterize birefringence of samples selected from the group consisting of a turbid sample, transparent sample, and microfluidic chip.

16. The fiber-based optical low-coherence reflectometer of claim 4, wherein the optical delay line includes a diffraction grating and dispersion control.

17. The fiber-based optical low-coherence reflectometer of claim 1, wherein light back scattered from the sample after traversing through the variable wave retarder is elliptically polarized.

18. The fiber-based optical low-coherence reflectometer of claim 5, wherein the connector is an angle-cleaved connector.

19. The fiber-based optical low-coherence reflectometer of claim 4, wherein the phase modulator is a Lithium Niobate waveguide electro-optic phase modulator.

20. The fiber-based optical low-coherence reflectometer of claim 4, wherein the phase modulator provides a stable carrier frequency and permits measurement of fast transient birefringence.

21. The fiber-based optical low-coherence reflectometer of claim 1, wherein the fiber-based optical low-coherence reflectometer is rotationally insensitive of the measured retardation of a birefringent sample.

22. A method for characterizing birefringence of a sample comprising the steps of:

creating a polarization-maintaining optical source path using a broadband light source;

creating a polarization-maintaining optical reference path that is optically coupled to a first collimator directed to an optical delay line with dispersion control;

creating a polarization-maintaining optical sample path that is optically coupled to a second collimator, a variable wave retarder, and a focusing lens, wherein the focusing lens focuses light on the sample;

creating a polarization-maintaining optical detection path optically coupled to a third collimator and a polarizing beam splitter, wherein the polarizing beam splitter is optically coupled to a first and second photodetectors that produce a first and second output signal, respectively;

connecting the polarization-maintaining source path, reference path, sample path and the detection path to a polarization-maintaining path coupler;

converting the first and second output signals from the polarization-maintaining optical detection path with an analog-to-digital converter; and

connecting a processor to the analog-to-digital converter for collection of birefringent data about the sample.

23. The method of claim 22, wherein the first and second output signals from the polarization-maintaining optical detection path initially pass through a bandpass filter and amplifier to produce a first and second filtered signals.

24. The method of claim 22, wherein birefringent data about the sample is selected from the groups consisting of retardation and orientation of the birefringent axes of sample and depth resolved birefringence.

25. The method of claim 22, wherein birefringence is characterized with a single or multiple measurements.

26. A polarization-maintaining optical fiber sample path optically aligned with a collimating lens, a variable wave retarder, and a focusing lens, wherein the focusing lens is disposed to focus light on a sample to characterize birefringence about the sample with rotation insensitivity of the measured retardation of the birefringent sample.

27. A polarization-maintaining optical fiber sample path optically aligned with a collimating lens, a quarter wave retarder, and a focusing lens, wherein the focusing lens is disposed to focus light on a sample and light back scattered from the birefringent sample after traversing through the quarter wave retarder is elliptically polarized.

28. The polarization-maintaining optical fiber sample path of claim 26 further comprising an optical catheter probe used for imaging.

29. The polarization-maintaining optical fiber sample path of claim 26 configured to interrogate a sensor.

30. A method of optically analyzing a sample comprising the steps of:

placing a sample in front of a polarization-maintaining optical sample path that is optically coupled to a first collimator, a variable wave retarder, and a focusing lens, wherein the focusing lens is disposed to focus light on the sample;

creating a polarization-maintaining optical source path to introduce light;

creating a polarization-maintaining optical reference path that is optically coupled to a second collimator, wherein the collimator is directed into a rapid scanning delay line to be used as a reference; and

detecting light changes on the sample using a polarization-maintaining optical detection path optically coupled to a third collimator and a polarizing beam splitter, wherein the polarizing beam splitter is optically coupled to a first and second photodetectors that produce a first and second output signals, respectively, wherein the first and second output signals are filtered and converted with an analog-digital converter to digital data about the sample;

wherein the polarization-maintaining optical source path, reference path, sample path and detection path are connected to a polarization-maintaining path coupler.

31. A system of characterizing birefringence of a sample comprising:

a broad bandwidth optical light source;

a polarization-maintaining optical source path incorporating a polarizing element and correlates optical signals in fast and slow fiber polarization channels and optically connects both channels to a polarization-maintaining path coupler;

a polarization-maintaining path coupler that separates light into polarization-maintaining optical sample and reference paths while maintaining energy separation of optical signals in the fast and slow fiber polarization channels;

a polarization-maintaining optical reference path optically connected to the polarization-maintaining path coupler and optically coupled to an optical delay line;

a polarization-maintaining optical sample path optically connected to the polarization-maintaining path coupler, wherein the polarization-maintaining optical sample path comprises a quarter wave retarder and a focusing lens, wherein the focusing lens is disposed to focus light on the sample;

said sample placed in front of the polarization-maintaining optical sample path from which birefringence is characterized;

a polarization-maintaining optical detection path optically connected to the polarization-maintaining path coupler and a polarizing beam splitter that is optically coupled to a first and second photodetectors that produce first and second output signals, respectively, wherein the first and second output signals are filtered and amplified;

an analog-to-digital converter connected to the filter-amplifier; and

a processor connected to the analog-to-digital converter.

32. A method for determining depth-resolved phase retardation of a sample birefringence comprising the steps of:

initially estimating pseudo fast axis orientation [$\phi_f(i=0)$, $\theta_f(i=0)$] and cone apex-angle [$\theta_o(i=0)$], wherein the fast axis orientation is $F(\phi_f, \theta_f)$ and the cone apex-angle is θ_o;

determining F and θ_o using a Levenberg-Marquardt method; and

computing the least square determination of depth-resolved phase retardation [$\delta(z, \Delta z)$].

33. A method for determining depth-resolved phase retardation [$\delta(z, \Delta z)$] of a sample comprising the step of:

computing $\delta(z, \Delta z) = N_p m$, wherein N_p is the number of data points about a sample recorded over optical depth Δz.

34. A method for determining an unbiased estimate of [$F(\phi_f, \theta_f)$, θ_o] comprising the steps of:

minimizing a residual function, wherein the residual function is

$$R(\varphi_f, \theta_f, \theta_o) = \sum_i \sin^2(\varepsilon_i); \textit{ where } \varepsilon_i = \cos^{-1}\left(\boldsymbol{S}_i \cdot \boldsymbol{n}(\varphi_f, \theta_f)\right) - \theta_o,$$

wherein ε_i is the shortest distance between an i'th data point (S_i) and an arc on a Poincaré sphere specified by [ϕ_f, θ_f, θ_o].

35. The method of claim 34, wherein the residual function is formed by the composite sum of distances (ε_i) on the Poincaré sphere formed between the data points (S_i) and the arc specified by [ϕ_f, θ_f, θ_o].

36. A fiber-based optical low-coherence reflectometer comprising:

a path coupler that separates light into sample and reference paths while maintaining energy separation of optical signals into fast and slow fiber polarization channels;

a source path comprising a first polarization-maintaining optical fiber having a first end and a second end, wherein the first end of the first optical fiber is coupled to a light source and the second end is connected to a polarizer that splits the light source into a first and second polarization channels with independent phase components; and a second polarization-maintaining optical fiber having a first end and a second end, the first end connected to the polarizer and the second end connected to the path coupler;

a reference path comprising a third and fourth polarization-maintaining optical fiber, the third polarization-maintaining optical fiber having a first end and a second end, the first end connected to the path coupler, the second end connected to a phase modulator; and a fourth polarization-maintaining optical fiber having a first end and a second end, the first end connected to the phase modulator, the second end to a connector and optically aligned with a first collimator that collimates light emitting from the second end of the fourth polarization-maintaining optical fiber into an optical delay line;

a sample path comprising a fifth polarization-maintaining optical fiber having a first and a second end, the first end connected to the path coupler, the second end to a connector and optically aligned with a second collimator that collimates light emitting from the second end of the fifth polarization-maintaining optical fiber to a variable wave retarder and a focusing lens, wherein the focusing lens is aligned to focus light on a sample; and

a detection path comprising a sixth polarization-maintaining optical fiber having a first end and a second end, the first end connected to the path coupler, the second end aligned with a third collimator that collimates light emitting from the sixth polarization-maintaining optical fiber onto a polarizing beam splitter, wherein the polarizing beam splitter splits the light from the sixth polarization-maintaining optical fiber into a first beam and a second beam that are mutually orthogonal and capable of producing a first and second output signal about the sample.